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The Frequency Content of the VIRGO/SoHO Lightcurves: Implications for Planetary Transit Detection from Space

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Abstract. Stellar micro-variability poses a serious threat to the capacities of space-based planet-finding missions such as *Kepler* or *Eddington*. The solar lightcurves obtained by the VIRGO PMO6 and SPM instruments on board SoHO from 1996 to 2001 have been studied in order to follow variability changes through the activity cycle. In all datasets, active regions-induced variability, below 2 μHz, is closely correlated to the BBSO Ca II K-line index. The PMO6 (total irradiance) data shows evidence for a meso-granulation component around $\tau \simeq 8 \times 10^3$ s, while all narrow-band SPM datasets (red, green and blue) show super-granulation ($\tau \simeq 5 \times 10^4$ s) but no meso-granulation. Both actvity and granulation related components have significantly smaller amplitudes in the red than in the blue channel. These results, coupled with available stellar data, allow us to generate simulated lightcurves with enhanced variability as a testbed for pre-processing and detection methods, and influence the case for using colour information in this kind of mission.

1. Introduction

Transit detection algorithms in photometric time series, developed by the COROT (Defaÿ, Deleuil, & Barge 2001), *Eddington* (Aigrain & Favata 2002) and *Kepler* (Jenkins, Caldwell, & Borucki 2002) teams are very effective in the presence of white noise, and show that the latter two missions could detect habitable Earth-sized planets in data with white noise only. However, the non-Gaussian, ill-known stellar variability can have amplitudes over an order of magnitude larger than an Earth-analogue transit. Simulations using PMO6 data and the Bayesian algorithm developed for *Eddington* show that the minimum detectable planet size changes to 3 $R_\oplus$ when Sun-like variability is introduced without sophisitcated filtering techniques[1] (Aigrain, Gilmore, & Favata, 2001). Variability will thus impact the choice of pre-processing techniques as well as target selection and colour information issues.

[1]Simulations for a K5V star with $V = 14.5$, 4 transits in the light curve

Pre-processing methods are already under investigation. After testing a highpass filter with some success, the *Eddington* team have developed a more optimized filter, based on a priori knowledge of the transit shape. Initial tests suggest it will be very successful, but realistic lightcurves with various levels of activity are needed for a quantitative assessment. The only star monitored with sufficient photometric precision and sampling is the Sun, which we use as a starting point.

2. Method

The power spectrum of the Sun's lightcurve contains, beside the sharp oscillatory peaks used in helioseismology, an underlying 'solar background'. It is mostly concentrated at low frequencies and has a complex, multi-component structure extending to a few mHz. It is commonly modeled as a sum of power laws (Harvey 1985, Andersen 1991, Andersen 1992, Harvey et al. 1993):

$$P(\nu) = \sum_{i=1}^{N} P_i(\nu) = \sum_{i=1}^{N} \frac{\mathrm{A_i}}{1 + (\mathrm{B_i} \times \nu)^{\mathrm{C_i}}}$$

Various authors (Harvey et al. 1993, Andersen, Leifsen, & Toutain 1994, Rabello Soares et al. 1997) found up to 5 components in total irradiance: active regions, with characteristic timescale $\tau = 1$ to 3×10^5 s; super-granulation ($\tau = 3$ to 7×10^4 s); meso-granulation ($\tau \simeq 8000$ s); granulation ($\tau = 200 to 500$ s); bright points ($\tau \simeq 70$ s). Interestingly, analysis of the narrow channel SPM data to date has shown no evidence for a meso-granulation component (Andersen et al. 1998, Pallé, Roca Cortés, & Jiménez 1999).

With the VIRGO dataset now spanning the interval from solar minimum to maximum, the evolution of the various components with the activity cycle can be studied. An algorithm has been developed to fit the Fourier Transform (FT) of lightcurve sections of duration L, adding components one by one until adding a component no longer improves the fit. A new section, offset from the previous one by a step S, is then fitted in turn, using the last fit as an initial guess. An example fit is shown in Fig. 1(a). Thus we monitor variations in amplitude, timescale and slope for each component and attempt to relate them to observables measured in many stars.

3. Results

The algorithm described above was run on the PMO6 and SPM data with $L =$ 180 days and $S = 20$ days, resulting in two components plus a third whose turnoff was unresolved at higher frequencies. A number of points of interest emerge from the results. In all 4 datasets the amplitude of the first component, with $\tau \simeq 1.3 \times 10^5$ s (active regions) increases from solar minimum to maximum and is correlated with the Ca II K-line index, indicator of chromospheric activity (see Fig. 1(b)). The amplitude of the second component also increases, but is not correlated to the Ca II index. In both cases, the red channel shows a lower amplitude than the blue and green channels. Noticeably, the timescales are

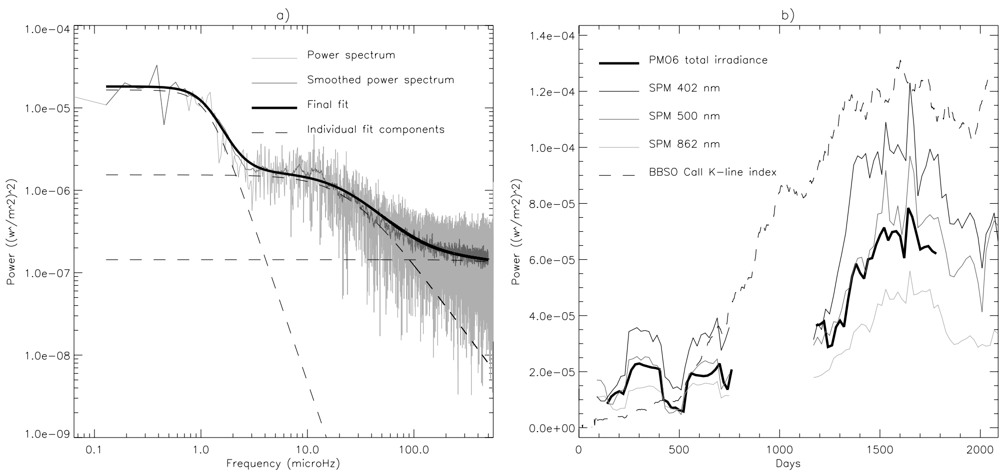

Figure 1. (a) Example fit to a 180 day section of PMO6 data. (b) Evolution of the amplitude of the active regions component between 1996 and 2001, using $L = 180$ days, $S = 20$ days. The BBSO Ca II K-line index has been smoothed over 180 days, scaled down and offset for clarity. The gap at around 1000 days correspond to a prolonged gap in the data.

different in the PMO6 and the SPM data. The difference is significant for the second, granulation related component, with $\tau \simeq 8 \times 10^3$ s (meso-granulation) and $\tau \simeq 5 \times 10^4$ s (super-granulation) for PMO6 and SPM data respectively. This may result from a difference in contrast between super- and meso-granulation in the different channels, as suggested by Andersen et al. (1998). The meso-granulation signal present in total irradiance may also be due to spectral features not included within the narrow SPM channels. This question will be investigated by examining the spectral content of the channels and comparing solar disk images to the components' evolution. The slopes are 3.8 (active regions) and 1.75 (granulation, both datasets), in good agreement with Andersen et al. (1998).

4. Discussion and future work

We have shown that indicators of chromospheric activity such as the Ca II K-line index provide a good proxy to the amplitude of the Sun's variability at low frequencies. As similar indicators are commonly measured in other stars, we may infer their expected variability level up to a few μHz. However, little theoretical or observational insight is yet available to relate granulation-type phenomena to stellar observables. Relating the observed components in the power spectrum to spectral and/or surface features may allow us to identify some new indicators of this type of variability.

In the mean time, a lightcurve 'simulator' is being developed, using known scaling laws between chromospheric indicators, rotation period and colour, in which we can realistically scale up the active regions component. In the absence of more information a variety of scaling laws will be tried for the granulation component. This will provide a thorough test of pre-processing techniques under development.

In the longer term missions such as MOST, MONS and COROT will provide an ideal dataset to calibrate a general micro-variability model[2]. Our understanding of the mechanisms behind low frequency, low amplitude stellar variability promises to improve vastly over the next few years.

Work is underway to quantify any increase in detection power gained from concentrating on the red part of the spectrum where we observe smaller variability, and from optimizing the filter bandwidth to exclude particularly variable spectral regions. These must be weighed against loss of photometric accuracy.

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[2] A proposal for the COROT Parallel Science Working Group, entitled *Hours-timescale stellar background variability and exo-planet transit detection prospects* (PI A. Collier-Cameron) has recently been accepted.